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Bed Occupancy Monitoring: Data Processing and Clinician User Interface Design

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***Abstract*— Unobtrusive and continuous monitoring of patients, especially at their place of residence, is becoming a significant part of the healthcare model. A variety of sensors are being used to monitor different patient conditions. Bed occupancy monitoring provides clinicians a quantitative measure of bed entry/exit patterns and may provide information relating to sleep quality. This paper presents a bed occupancy monitoring system using a bed pressure mat sensor. A clinical trial was performed involving 8 patients to collect bed occupancy data. The trial period for each patient ranged from 5-10 weeks. This data was analyzed using a participatory design methodology incorporating clinician feedback to obtain bed occupancy parameters. The parameters extracted include the number of bed exits per night, the bed exit weekly average (including minimum and maximum), the time of day of a particular exit, and the amount of uninterrupted bed occupancy per night. The design of a clinical user interface plays a significant role in the acceptance of such patient monitoring systems by clinicians. The clinician user interface proposed in this paper was designed to be intuitive, easy to navigate and not cause information overload. An iterative design methodology was used for the interface design. The interface design is extendible to incorporate data from multiple sensors. This allows the interface to be part of a comprehensive remote patient monitoring system.**

Keyword-components; bed occupancy, bed entry/exit, bed pressure mat, ultrasound sensors, clinician user interface .

I. Introduction

The monitoring of patients in a clinical or home setting is becoming a growing part of the health care system. Various biological and environmental signals like ECG, heart rate, breathing rate, cough, blood pressure, glucose, sleep, mobility, room temperature etc. may be monitored [1] [2]. Monitored signals provide clinicians with information about long term trends in patient conditions, and may identify deterioration before it becomes an emergency. In addition they may allow clinicians to measure the effectiveness of a treatment.

Bed occupancy monitoring provide clinicians with information regarding a) sleep interruption during the night, b) number of hours of bed occupancy during the day and night, c) changes to morning bed exit routine etc. Sleep pattern monitoring is useful for the monitoring of many medical conditions as well as for quality of sleep [3] [4] [5].

With the increasing ability to simultaneously monitor multiple patients' biological signals over a long period of time, clinicians could easily become overloaded with patient data. The data needs to be appropriately analyzed so that the long term trends and deviations are easily visible at first glance. This data also needs to be presented to the clinicians in a user friendly manner; otherwise this could lead to the rejection and/or under-utilization of the patient monitoring system [6] [7]. A participatory design approach [8],[9] was used in order to determine how to properly process and display the bed occupancy data to the clinicians.

A Clinician User Interface (CUI) was developed as a part of this work to show how the monitored data could be displayed to clinicians. The data used in this paper was obtained from a clinical trial using the bed occupancy monitoring system as a part of a rehabilitation study done in collaboration with the Élisabeth Bruyère Hospital of the Bruyère Continuing Care in Ottawa. The clinical trial was conducted at 8 patient homes for a period of 5-10 weeks per patient. The CUI is very generic and can be expanded to handle data from a variety of sensors and for a number of different medical conditions. The integration of multisensory data into the CUI is also demonstrated in this paper.

II. Bed Occupancy Monitoring System

To measure the bed occupancy of a patient, a pressure sensitive mat by S4 Sensors Controls Inc called Bed Occupancy Sensor (BOS™) was used. The BOS™ is a waterproof sensor pad that is placed under a client's mattress in the patient's home. Each bed mat has 24 pressure sensors in an 80 cm by 30 cm semi-rigid pad. The data being recorded by the bed mat sensor is a relative measure of force being applied to the mat. Fig. 1 shows the block diagram of the bed occupancy monitoring system.

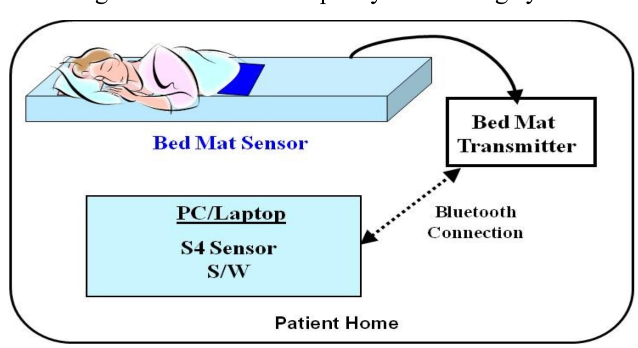

Figure 1. Block diagram of the bed occupancy monitoring system

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The system comprises of one bed mat, a PC to collect and store the data, and a Bluetooth box to provide the link between the bed mat and the PC. The consent was obtained from 8 patients being treated at an out-patient clinic of the Élisabeth Bruyère Hospital of the Bruyère Continuing Care in Ottawa.

Once the consent was obtained the bed mats were installed at the patients' homes to measure bed occupancy data. The data was collected over a period of 5 to 10 weeks depending on patients' treatment at the Hospital.

The system was installed in an unobtrusive way and did not interfere with the patient's daily activities. Once installed the data collection did not require any intervention and ran with no interruptions until the end of the trial period. At the end of the trial period the bed mats and PCs were brought back to the lab. A complete analysis was performed using Matlab algorithms developed by our team to extract the bed occupancy parameters. The occupancy data provides information about timing of the bed entry/exit, number of entries/exits per day and amount of time spent in bed.

III. Bed Occupancy Data Analysis

Since the bed mat is installed under a patient's mattress the bed occupancy algorithms need to account for different mattress and patient weights. The analysis algorithm calculates the base value when no one is present in the bed (only the mattress's weight) using one minute of pressure data P_n (1).

$$P_n = \sum_{s=1}^{24} X_s \tag{1}$$

Where P_n is the sum of the pressure values of 24 sensors for one sampling period, and X_s represents the pressure value of a sensor 's' where 's' goes from 1 to 24. The base value β, is the average of the 24 pressure sensors (2). The average is calculated using the number of samples corresponding to 1 minute of data collection. At a sampling frequency of 10 Hz the total number of samples for a 1 minute period is given by N = 600.

$$\beta = \frac{\sum_{n=1}^{N} P_n}{N} \tag{2}$$

The base value β, is then combined with the minimum preset value of τ to establish a threshold value T as shown in (3). This threshold value T is used by the algorithms to detect the presence or absence of a person in the bed and obtain the time stamp for each bed entry/exit. The value of τ is set in the algorithms based on the patient's weight and according to the sensitivity needs for the data analysis. A lower value of τ corresponds to a higher sensitivity of detection. During the first minute of the system setup, the system adaptively evaluates the value of β with no patient in the bed.

$$T = \beta + \tau \tag{3}$$

Fig. 2 shows the pressure data values obtained from the bed mat for different pressure applied by a patient. The base value β as well as the value of τ is shown in Fig. 2. The τ value can easily be shifted up or down depending on the sensitivity needs.

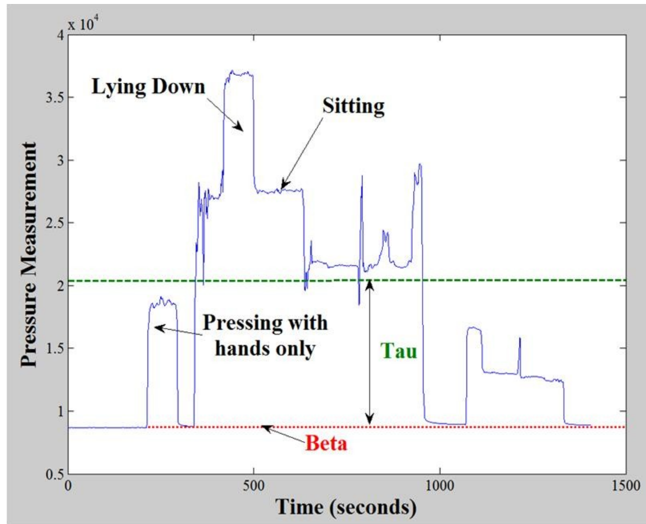

Figure 2. Pressure data obtained from the pressure sensitive mat

IV. Participatory Design Approach For Data Analysis

The bed occupancy data can be analyzed to provide clinicians with an indication of a patient's quality of sleep, number of bed entry/exit during the day and night as well as long term trends in bed occupancy. This analyzed data may be used by clinicians to identify the root cause of the changes in bed occupancy pattern.

In order to minimize information overload and not affect a clinician's productivity, the information needed to be presented in a manner that is intuitive to clinicians. A participatory design approach was followed in deriving bed occupancy parameters from the clinical trial data. A flow chart of the design methodology is shown in Fig. 3.

A clinician's input was used to analyze the raw data and derive different bed occupancy parameters and trends such as the number of bed exits per night, maximum, minimum and standard deviation for the number of bed exits per week, bed exit time, and continuous hours of bed occupancy.

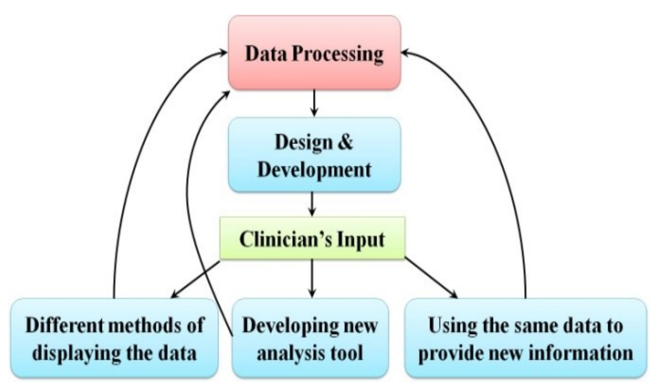

Figure 3. Participatory design approach used in trend analysis extraction of clinical data

These parameters can be used as an indication of quality of sleep, correlation of exit time night over night, and number of bathroom visits during the night.

Multiple iterations of the algorithm prototypes were done until the bed occupancy parameters and display format were finalized to meet the clinicians' usability requirements. Using the analysis algorithms, over 9408 combined hours of bed occupancy clinical trial data were analyzed.

V. Statistical Analysis Of Bed Occupancy Data

It was determined that the number of exits per night and the average number of exits per week with minimum and maximum number of exits per day were important in identifying an improvement in a patient's sleep quality and response to a particular treatment. Fig. 4 shows the number of exits per night and Fig. 5 shows the average number of exits for each week, with minimum and maximum number of exits per day. The day time was defined as 9:00am – 9:00pm; however this parameter can be easily adjusted in the algorithms.

The exits that lasted less than 1.5 minutes as well as the entries that were less than 30 minutes were removed as they were considered unrelated to bed rest interruption. The number of exits per night does not include the exit in the morning when a patient gets up to start their day. This was done to separate bed entries/exits that happened during a patient's sleeping hours only.

Another type of information that was determined to be useful to clinicians is the time of bed exit. The time of bed exit may indicate the pattern of patient's bed exits during the night. The clinician may adjust the treatment if such pattern is considered clinically important. Comparing the time of bed exit for different weeks may also indicate to the clinicians whether a patient's condition is improving or not. Fig. 6 compares the time of bed exit for 4 different weeks.

It was also determined that the number of hours of consecutive bed occupancy was useful to clinicians. A similar analysis was performed in order to obtain and display the data showing consecutive hours of bed occupancy as seen in Fig. 7.

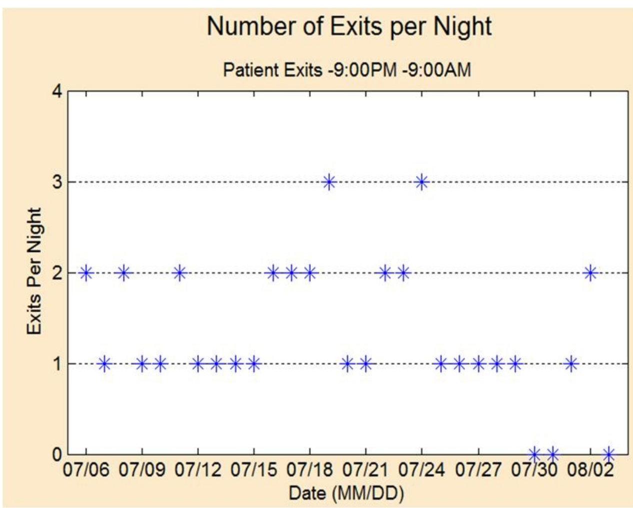

Figure 4. Number of exits per night

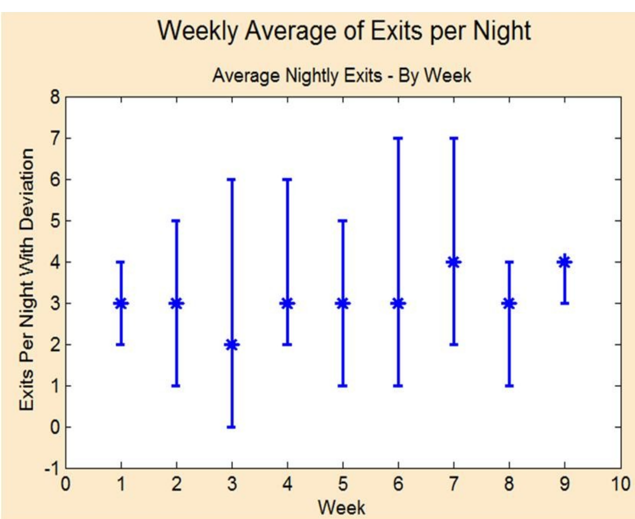

Figure 5. Average number of exits per week with minimum and maximum number of exits per day

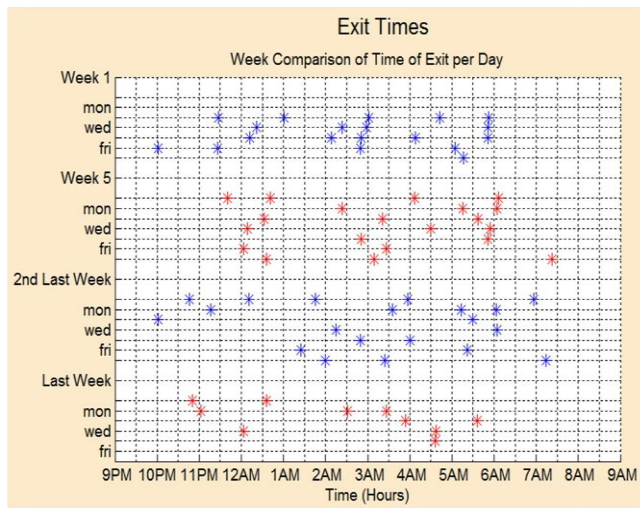

Figure 6. Time of bed exit

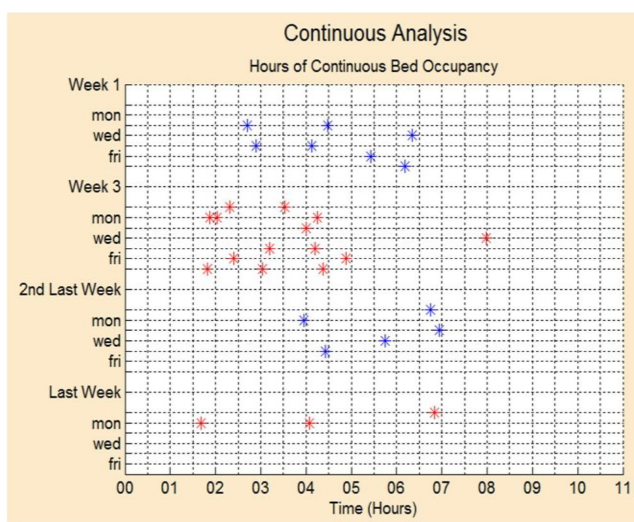

Figure 7. Consecutive hours of bed occupancy

VI. Clinician User Interface Display

Although a lot of research has been conducted for sensors, networks connecting sensors and related technologies, not enough attention has been focused on the usability of patient monitoring systems. Usability is critical if the patient monitoring systems are to gain acceptance by the clinical community. The acceptance of patient monitoring systems by clinicians will depend on if the users (clinicians) perceive the user interface as easy to learn with minimal training, straight forward to navigate, accessible on multiple devices such as smart phones, laptop and cell phones, as well as if the data is presented in an intuitive manner and does not cause information overload [8] [9] [10]. It must also integrate seamlessly into the clinician's workflow.

A design of a Clinician User Interface (CUI) that will lead to wider acceptance and penetration of the patient monitoring system is a critical component of the patient monitoring system. An iterative design methodology was used for the CUI development [10]. The main widow of the finalized CUI is shown in Fig. 8.

The CUI home page shows the patient's name, the clinician attending the patient and has buttons to access more detailed patient information. The CUI provides clinicians with access to sub-windows via Vitals, Bed Occupancy Analysis and Sit-to-Stand (StS) Analysis buttons as well as an area where any significant deviations or critical events are reported. The CUI home page may be modified to allow different sensor data to be incorporated into the CUI display. The methodology of the CUI design is however generic and flexible enough to ensure that any modifications to the CUI display meets the clinician's requirements.

The sub-windows allow clinicians to further investigate a particular data by navigating to that specific sub-window, e.g. the Bed Occupancy Analysis sub-window allows clinicians to investigate the data related to the bed occupancy parameters. More sub-windows will be added as more sensors are added to the patient monitoring system.

The Bed Occupancy Analysis button opens up a new sub-window where 4 types of plots are available to the clinician using 4 buttons, as seen in Fig. 9. These plots correspond to the plots shown previously in Fig. 4, Fig. 5, Fig. 6 and Fig. 7.

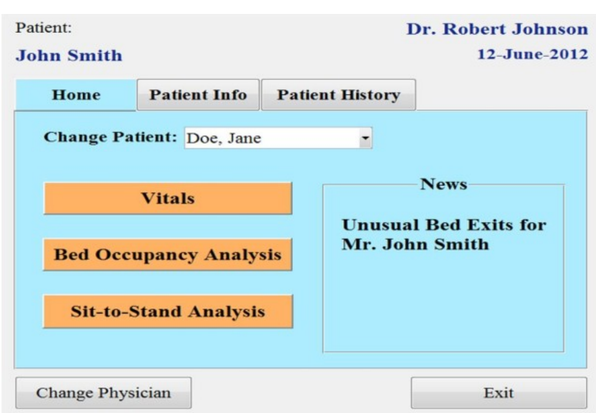

Figure 8. CUI home page (main window)

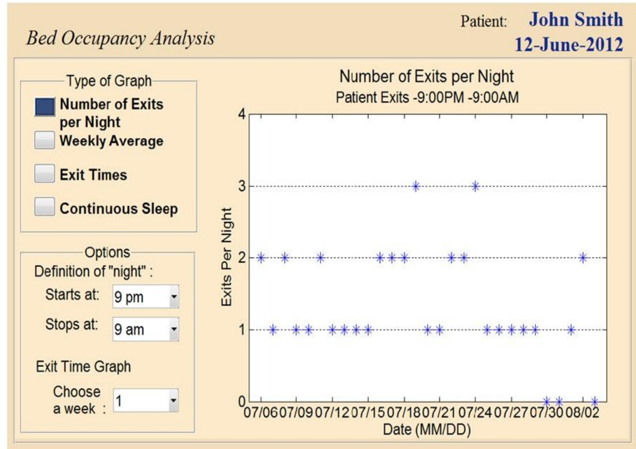

Figure 9. CUI sub-window for bed occupancy analysis (exits per night)

VII. Integrating Bed Occupancy Data With Unassisted Sit To Stand Data In CUI Design

Our CUI design is generic and can be expanded to incorporate other sensor data. Here we demonstrate how the CUI design can be easily extended to incorporate two types of data; bed occupancy data and Sit-to-Stand (StS) transfer timing data, from two different sensors.

Monitoring patients' StS transfer times to establish a patient mobility trend is important for measuring a patient's recovery after an operation, a stroke, or an injury [11] [12]. It is important to separate StS transfers which are unassisted and which are assisted by a third party to measure the progress/degradation in a patient's mobility.

An ultrasound based system can be used along with a StS transfer timing system using bed mat to separate assisted and unassisted transfers [13].

Our CUI design incorporates the data from the StS system under the StS Analysis button as seen in Fig. 8. Pressing the StS Analysis button opens a new sub-window where the assisted and unassisted exits can be viewed. Fig. 10 shows how StS transfer timing data obtained from the bed mat and the ultrasound sensor system [13] can be used by clinicians to isolate unassisted transfers. The transitions without any assistance are shown in green and the transitions in which assistance was provided are shown in red.

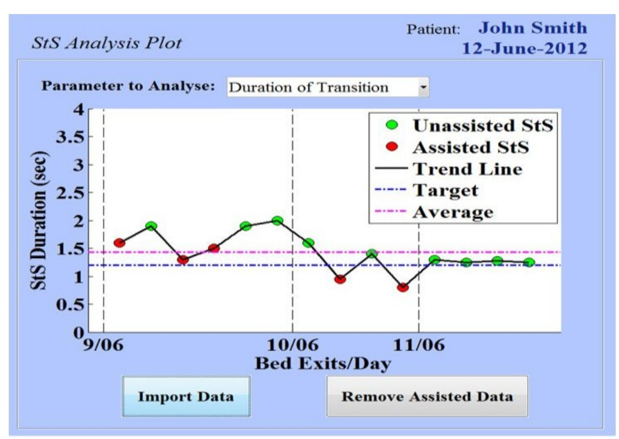

Figure 10. StS analysis window with assisted and unassisted data points

The clinician has the ability to zoom in on particular regions and eliminate all the assisted data points by clicking on the Remove Assisted Data button.

By removing all assisted data points, a new trend line is established as seen in Fig. 11. The assisted and unassisted StS transition timing data used in this paper is simulated data obtained in a lab setting.

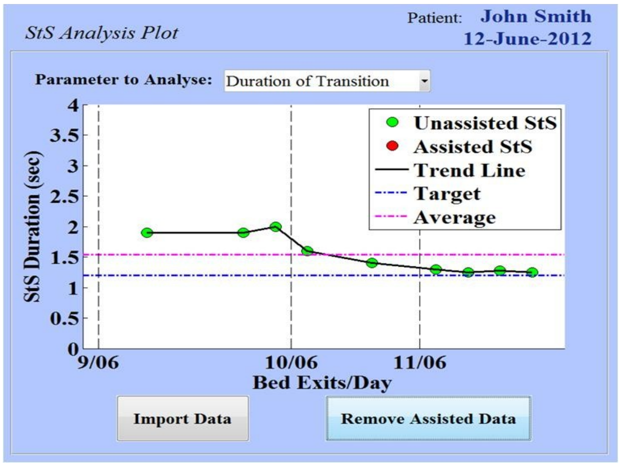

Figure 11. StS analysis window with assisted data points only

VIII. Conclusions

Monitoring bed occupancy is a useful indicator for clinicians. Algorithms have been developed to derive parameters like the number of bed entries/exits per day, the average number of entries/exits, the entry/exit times, and the amount of continuous bed occupancy using bed occupancy data. A clinical trial involving 8 patients was conducted to obtain bed occupancy data over a 5-10 week period. An iterative design approach was used to develop algorithms based on clinicians' feedback. A CUI has been developed in order to display the analyzed bed occupancy data to clinicians in a format that is user friendly, intuitive to navigate and does not overwhelm the clinician. The CUI design was expanded to display data from the Sit-to-Stand transfer timing monitoring system as well as from the bed occupancy system. The CUI will be further developed to incorporate the display data from other types of patient monitoring systems such as ECG, breathing rate, and heart rate.

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